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Validation for Space Code Program in Application to Pipe Flow Experiments- Horizontal Stratified Flow Models

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1. Introduction

As a part of the Thermal Hydraulics Safety Analysis Department of Korean Atomic Energy Research Institute (KAERI), we are investigating PWR Hot leg behavior. To improve knowledge of horizontal stratified flow two-phase flow droplet phenomena, validation for experimental data dedicated from the REGARD, CEA experiment was performed using SPACE (Safety and Performance Analysis Code for Nuclear Power Plants). Using newly developed models for droplet deposition and entrainment results from experimental data was simulated well. Applications regions and past experiments related to this area were also analyzed.

2. Methods and Results

In this section some of the techniques used to model the two-phase flow behavior are described. The two phase flow behavior areas of interest include droplet entrainment and deposition, flow regime, and interfacial area of liquid film and air.

2.1 Pairing of Entrainment and Deposition Models

Experimental data was obtained from the REGARD experiment by CEA, Grenoble [3]. Data was further analyzed and validated with SPACE simulation program. Due to the nature of two-phase flow existing models for entrainment and deposition did not match well against experimental data. This difference can be attributed to the large diameter size of this experiment compared to the relatively small diameter pipe experiments from which existing models and correlations were developed. Also in previous horizontal flow models, gravity was not accounted for the deposition of droplets. The pairing of entrainment and deposition source terms is crucial for successful modeling of droplet mass flow rate. Combining the adoption of a new developed model that accounts for gravity and diffusion from Neiss & Coraline [2] and accounting for the effect of diameter size on the concentration of droplets, a deposition model was obtained and validated well in this application region. Entrainment rates were also validated by implementing a revised interfacial area term which accounts for a curved interface of the liquid film [4].

2.2 Effect of Diameter on Droplet Deposition

The effect of a large diameter pipe on droplet deposition can be seen by experimental data from REGARD. In previous past pipe small diameter size experiments the size never exceeded to the point where the convergence of droplet mass flux to 0 kg/s occurs (along the vertical axis of a cross section of the pipe) so it was safe to assume the concentration was nearly uniform amongst the whole pipe cross section area. The figure below is provided to give a better visual understanding of this concept:

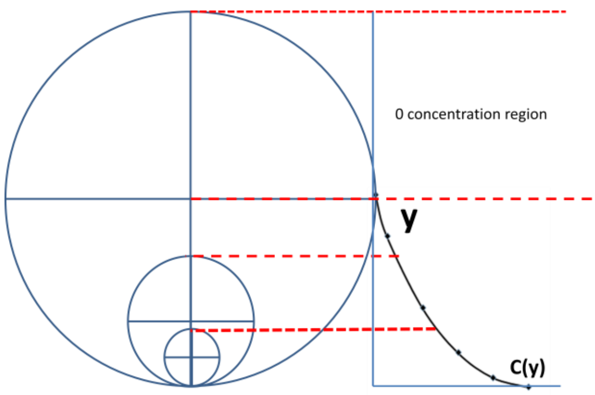

Fig. 1. Pipe Diameter Effect on Droplet Concentration

To adjust for this parameter a modified cross sectional area has to be implemented for the concentration term in the deposition rate. Previous models assume the whole cross section as the area where droplet deposition occurs. This assumption is safe when droplet concentration is nearly uniform.

$$C = \rho\alpha_d = \frac{\dot{m}_d}{V_d A} \quad (1)$$

When the pipe diameter exceeds a certain value the non uniformity of droplet concentration has an effect on deposition rate. The newly suggested modeling of concentration area is listed as follows:

$$A = A_{pipe} * \left(\frac{A_{pipe}}{A_{crit}}\right)^{-1} = A_{crit} \quad (2)$$

$$A_{crit} = f(D_{pipe}, j_g, j_l) \quad (3)$$

where concentration area is a function of critical area and air/gas velocity. It is physical reasonable to assume that because the droplet concentration area of interest for horizontal flow is towards the bottom half of the pipe for REGARD, the cross sectional area where deposition occurs happens only in this bottom region. Thus, increasing the concentration magnitude when compared to using total cross sectional area of the pipe.

2.3 Effect of Gravity on Droplet Deposition

When analyzing Neiss and Coralines' droplet deposition modeling it can be seen that gravity has a significant effect. The order of magnitude is also significantly larger than the diffusion term modeling. The implementation of this model paired with existing (Lopez) yields better results than previous modeling. However, some assumptions were made for the validation in SPACE code. When accounting for the particle relaxation coefficient a droplet diameter size was imposed based off of experimental data. The droplet sizes from experimental data were of much greater magnitude than that of SPACE Code calculations (~5x).

2.4 Entrainment Modeling

For consideration of the entrainment modeling, two different approaches were implemented into SPACE. Neiss and Coraline assumed fully developed flow and imposed constant values for entrainment rates. At fully developed flow the equation can be represented as the following for entrainment rate:

$$\frac{\partial \dot{m}_d}{\partial x_{|x\to\infty}} = 0 \Leftrightarrow \Gamma_E = \frac{k_D \dot{m}_d}{U_d \pi R^2} \qquad (4)$$

This approach is reasonable, however entrainment rates that were imposed do not match well with experimental data. This approach, when paired with the deposition modeling, does yields great results for mass flux rates of droplets as seen in Figures 1 and 2.

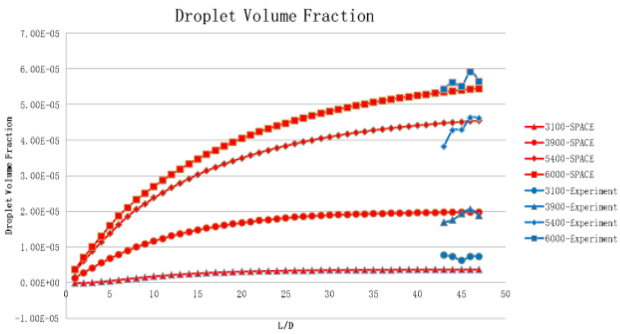

Fig. 2. Droplet Mass Flux Along the Axial Location of a Horizontal Pipe. REGARD Experimental Values and SPACE Calculations. Low Liquid Injection Speed.

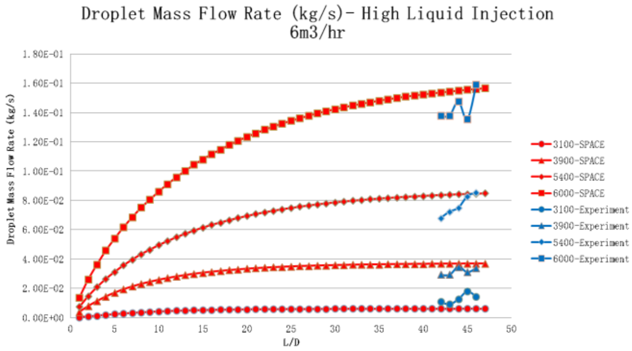

Fig. 3. Droplet Mass Flux Along the Axial Location of a Horizontal Pipe. REGARD Experimental Values and SPACE Calculations. High Liquid Injection Speed.

The second approach uses existing entrainment model [1] and includes a new interfacial area term currently being studied at Pusan national university [4]. The interfacial area term accounts for a curved interface as opposed to a straight interface in previous modeling. The curvature of the interfacial area is a function of diameter size, air/gas velocity. The entrainment rate is expected to improve results when matched against experimental data with the new developed equation. Also, the pairing of this model and Neiss and Coraline deposition rate model yields fair results for droplet mass flux.

3. Conclusions

The study of droplet behavior in horizontal stratified has much room for improvement, however more experimental data is needed. Finding a relation for where diameter of the pipe has an effect on concentration can help create a better deposition model that can be applied in regions outside of experimental conditions of REGARD. Also, investigation of the curvature of interface between air/gas and liquid film also can improve entrainment modeling.

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